CHAPTER 5

EXTERNAL COMPONENTS

5.1 INTRODUCTION

External components of an air cleaning system include fans, ductwork, dampers, louvers, housings, stacks, instruments, and other miscellaneous accessories that are associated with the movement, control, conveying, and monitoring of the air or gas flow.

This chapter contains information on the design, fabrication, materials, and codes and standards requirements/considerations for air cleaning system external components for nuclear facilities. Additional information can be found in Chapters 2 and 4, as well as ASME Code AG-1.[63]

5.2 DUCTWORK

This section will address the functional design, mechanical design, materials, coatings, supports, acoustic considerations, leakage, vibration considerations, and applicable codes and standards for ductwork for nuclear facilities.

5.2.1 FUNCTIONAL DESIGN

The sizing and layout of ductwork to provide desired air distribution, ventilation rates, transport velocities, and other functional requirements of the ventilation system are covered by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) handbooks,[1, 2] the American Conference of Governmental Industrial Hygienists' (ACGIH) *Industrial Ventilation,*[3] and American National Standards Institute (ANSI) Z9.2.[4] The purpose of this section is to review the physical aspects of the duct system in relation to nuclear air cleaning and treatment. The least expensive first-cost duct layout may not be the most economical when the total annual cost of operating the system is considered. Short-radius elbows and other shortcuts in ductwork may seriously increase system resistance, which could require, for example, the use of a larger fan and/or fan motor with resulting higher operating costs, or conversely, they could make it impossible for the system, as installed, to operate at the desired level of performance. The physical layout of ductwork in a building is often compromised to conform to the confines of a building structure or design. This may be unavoidable when installing new ducts in an existing building. In new construction, consideration should be given to providing adequate space and optimizing the duct layout configuration in the earliest phases of building layout, i.e., long before the building design has been finalized. Adequate access (as described in Chapter 4) to filter housings, fans, dampers, and other components is vital to maintainability and testability. Allowance of adequate space for well-designed elbows, transitions, and fan inlets and outlets is vital to proper operation.

5.2.2 MECHANICAL DESIGN

Duct cost is influenced by the size and quantities of ductwork, construction materials, coatings used for protection against corrosion, construction methods (seams, joints, etc.), air-tightness requirements, erection sequence (including consideration of space limitations, post-erection cleaning requirements, etc.), and the number and type of field connections and supports (hangers, anchors, etc.) required. Consideration should be given to future modification, dismantling, and disposal of contaminated ductwork, particularly in the design of systems for commercial nuclear power plants, laboratories, experimental facilities, and other operations where change-out of the ductwork or removal for maintenance can be expected. Provision for adding on or changing ductwork is a consideration that is often overlooked in initial design.

Where space permits, a round duct is generally preferred to a rectangular duct because it is stronger (particularly under negative or collapsing pressure); is more economical for the high-pressure construction often required for nuclear applications; provides more uniform airflow; and is easier to join and seal than a rectangular duct. The principal disadvantages of round duct are that it makes less efficient use of building space and it is sometimes difficult to make satisfactory branch connections. Any duct system that carries radioactive material, or that could carry radioactive material under upset conditions, should be classified, designed, and constructed in accordance with the requirements of United States Nuclear Regulatory Commission (USNRC) Regulatory Guides 1.52[7] (Nuclear-Safety-Related) or 1.140[8] (Non-Safety-Related) Specific Requirements for the performance, design, structural load combinations, construction, inspection, and shop and field fabrication acceptance testing for ductwork, ductwork accessories, and ductwork supports can be found in American Association of Mechanical Engineers (ASME) AG-1, Section SA.[63]

The level of radioactivity will largely determine the quality of duct construction required. Although it is sometimes assumed that all leakage in negative pressure ductwork will be in-leakage, this is not necessarily true. In the event of fire or explosion in a contained space (room, enclosure, hot cell, glovebox, or containment structure) served by the system, ductwork can become positively pressured, resulting in out-leakage). Out-leakage can also be caused by a rapidly closing damper or by dynamic effects (in a poorly laid-out system) under normal operating conditions. Under system shutdown conditions or during maintenance, the possibility of out-leakage from normally negative-pressure ductwork also exists. The engineer must consider these possibilities in the design and specification of permissible leak rates for negative-pressure portions of safety-related systems (ASME AG-1, Section SA, "Ductwork,"[63] contains an in-depth discussion on duct leakage). In addition, ducts that normally carry clean air can sometimes become contaminated. Ducts should be sized for the transport velocities needed to convey all particulate contaminants without settling. Recommended transport velocities are given in Section 5 of *Industrial Ventilation*.[2] Ducts for most nuclear exhaust and post-accident air cleanup systems should be sized for a minimum duct velocity of 2,500 fpm.

ASME AG-1, Section SA, "Ductwork," Non-Mandatory Appendix SA-C, Article C-1300[63] contains recommendations for ductwork construction standards. This paragraph recommends the Sheet Metal and Air Conditioning Contractors National Association's (SMACNA)[5] ductwork construction standards. Note that these standards do not incorporate structural design requirements. These standards must be evaluated for structural capability and adjusted as necessary to meet the requirements of ASME AG-1, Article SA-4000[63] and any other facility-specific requirements.

For ducts that are fabricated by welding, a minimum of No. 18 U.S. gage (preferably No. 16 U.S. gage) sheet metal is recommended from experience because of the difficulty of making reliable welds in thinner material. Because a nuclear facility may contain spaces of widely differing potential hazard levels (see confinement zoning discussion, Section 2.2.9), the type of duct construction required may vary from one part of the plant to another. The following questions must be answered to establish the type of duct construction needed for a particular application.

- Is the system nuclear-safety-related?
- If the system is nuclear-safety-related, is the level of radiation that exists in the duct, or the level that could exist in the duct in the event of a system upset, low, intermediate, or high?
- Must the air cleaning system remain operable in the event of a system upset (power outage, accident, malfunction) or can it be shut down?
- Where will the ductwork be located in relation to (1) the contained space served by the system and (2) the occupied spaces of the building? [Building spaces that are not normally occupied, but are occasionally entered for repair or service of equipment, are considered to be occupied.]
- Is the system once-through or recirculating?
- Is it an Engineered Safety Feature (ESF) system (as defined by USNRC Regulatory Guide 1.52[7]) that is intended to mitigate the consequences of an accident?

- What are the environmental considerations (e.g., pressure, temperature, corrosion, etc.)?

Depending on the answers to these questions, the duct should be constructed to conform to one of the several grades outlined in **TABLE 5.1** and the leaktightness recommendations of ASME AG-1, Section SA, Nonmandatory Appendix SA-B.[63] Recommended construction requirements are categorized as described below.

Level 1. In accordance with SMACNA's "HVAC [Heating, Ventilation, and Air Conditioning] Systems-Duct Design,"[5] (with the exceptions that button-punch and snap-lock seam and joint construction are not permitted), these constructions are considered unsuitable even for low-pressure construction.[9] Companion-angle or bolted (or screwed) standing-seam transverse joints are recommended. Standing edges of seams or joints and reinforcement should be on the outside of the duct.[10] [Use of Level 1 ductwork is limited to systems serving administrative areas and other non-safety-related applications in which maximum static pressure does not exceed 2 in.wg.]

Level 2. In accordance with SMACNA's "HVAC Systems-Duct Design,"[5] the use of Level 2 ductwork is limited to systems serving administrative areas, as well as Zone I and II areas in which the radiotoxicity of materials that are handled or could be released to the ductwork does not exceed hazard class 2 (see Tables 2.3 through 2.5), and in which negative pressure does not exceed 10 in.wg. The following exception apply: (1) button-punch and snap-lock construction are not permitted; (2) only bolted flanged joints, companion-angle flanged joints, welded-flanged joints, or welded joints are permitted for transverse connections; (3) tie rods and cross-braking are not permitted on negative-pressure ducts; (4) standing edges and reinforcement of seams and joints should be on the outside of ducts only; (5) sheet-metal thickness and reinforcement of negative-pressure ducts should be in accordance with ASME AG-1, _Article SA-4000, "Duct Design;"[63] and (6) radiation-resistant sealants (e.g., silicone room-temperature vulcanizing) are used as required in the makeup of nonwelded seams and in penetrations of safety-related ductwork. See **FIGURES 5.1** through **5.4** for examples of seams, joints, gaskets, and sealing of companion angle joint corners.

Level 3. This is the same as Level 2, with the exception that (1) transverse joints must have a full-flanged face width and use 1/4-in.-thick gaskets made of American Society of Testing and Materials (ASTM) D1056[11] grade 2C2 or 2C3 cellular neoprene; grade 2C3 or 2C4, 30 to 40 durometer, Shore-A, solid neoprene; or an equivalent silicone elastomer with interlocking notched corners; and (2) nonwelded longitudinal seams, transverse joints, or the entire exterior may have hard-cast treatment (polyvinyl acetate and gypsum tape system) or comparable fire-resistant, corrosion-resistant, radiation-resistant, nonpeeling, leaktight treatment.

Level 4. This level requires all-welded construction with sufficient mechanical transverse joints to facilitate coating (painting), erection, and future modification and/or dismantling. Mechanical transverse joints must conform to **FIGURE 5.2**. For sheet-metal thickness and reinforcement, see ASME AG-1, Section SA, Non-mandatory Appendix SA-C, Article C-1300.[63]

Level 5. Level 4 ductwork meets requirements for leaktightness as determined in ASME AG-1, Section SA, Non-mandatory Appendix SA-B[63] or the requirements of the "American National Standard for Pressure Piping"[12] or the ASME "Boiler and Pressure Vessel Code."[13]

Table 5.1. Guide for Selecting Recommended Duct Construction Levels for Various Applications in Nuclear Facilities

Contamination level and/or function[b]	Operating mode[c]	System type, duct location — Outside contained space, all systems, duct located in: Zone IV	Zone III	Zone II	Zone I	HVAC,[d] supply,[c] recirculating portion within contained space
None, supply, HVAC[d]	A	1	1	2	2	2
	B	1	1	1	1	1
Low (class 4)	A	3	2	2	2	2
	B	1	1	2	2	1
Moderate (class 3)	A	4	3	2	2	2
	B	4	2	2	2	1
High (class 2)	A	4	4	4	4	2
	B	4	4	4	4	2
Very high (class 4)	A	4	4	4	4	2
	B	4	4	4	4	2
Process off-gas	A	5	5	5	4	2
	B	5	5	4	4	2
Controlled atmosphere	A	5	5	5	5	5
	B	5	5	5	5	5
ESF control[g]	A	4	4	4	4	2[h]
ESF control room	A	4	4	4	4	2[h]
Other ESF	A	4	3	3	3	2[h]

Notes:
[a]Duct construction Level 1: SMACNA low velocity; Level 2: SMACNA high velocity; Level 3: improved SMACNA high velocity; Level 4: welded; :Level 5: pipe or welded duct, zero leak.
[b]Contamination levels (from Table 2.1).
[c]Operating mode: A – system to operate following upset or accident; B – system shutdown in event of upset or accident.
[d]HVAC, building enclosure zones, from Table 2.3 and Section 2.2.1.
[e]Contained space: the building area or enclosure served by the system.
[f]Inert gas, desiccated air, or other controlled medium.
[g]HGTs, shield building exhaust, or other primary or secondary containment post-accident air cleanup systems.
[h]Duct must be structurally designed to function following a design basis accident or safe shutdown earthquake.

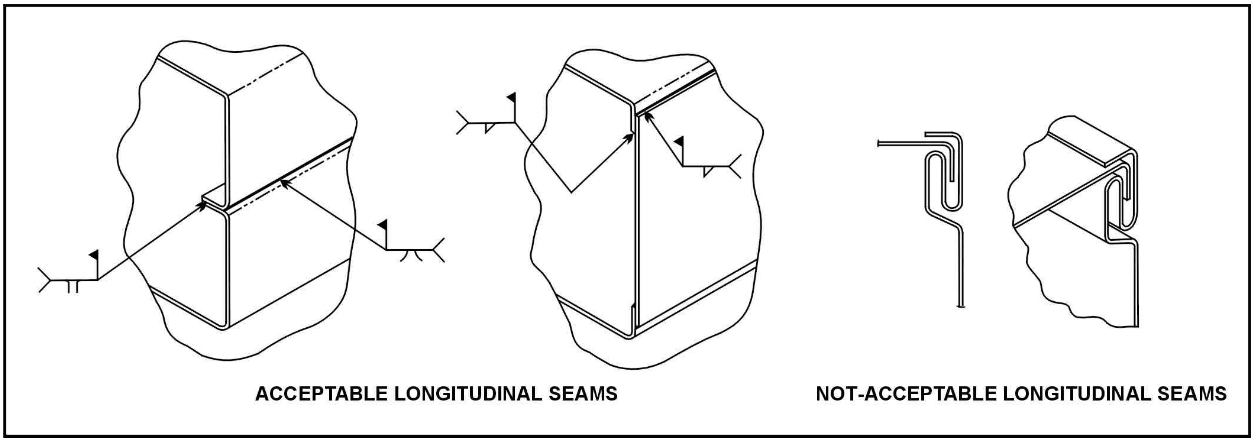

Figure 5.1 – Leakage Class 1 Duct Seams.

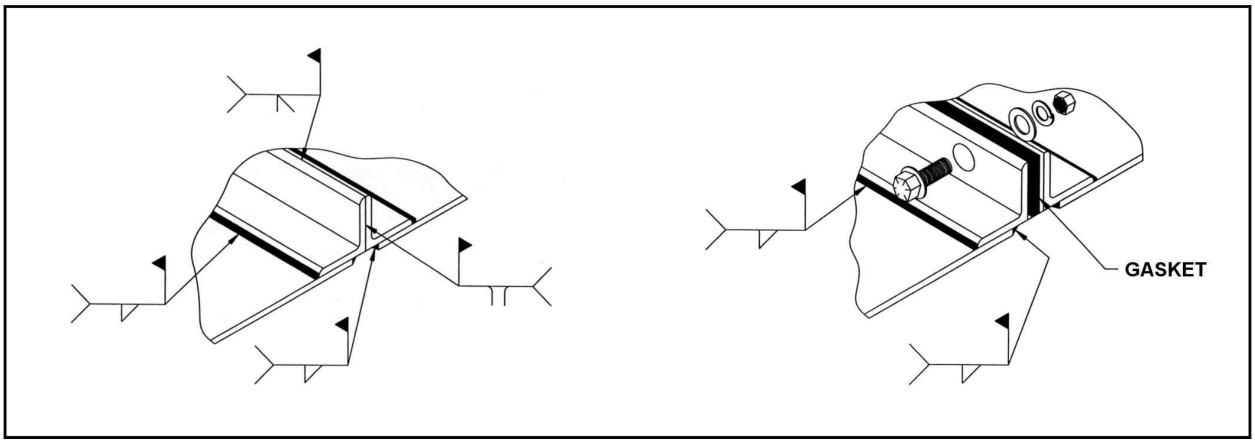

Figure 5.2 – Traverse Joints

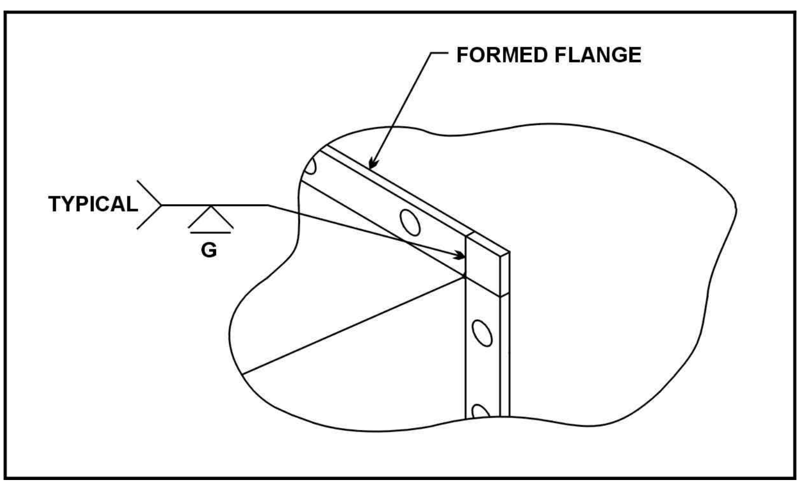

Figure 5.3 – Formed flange.

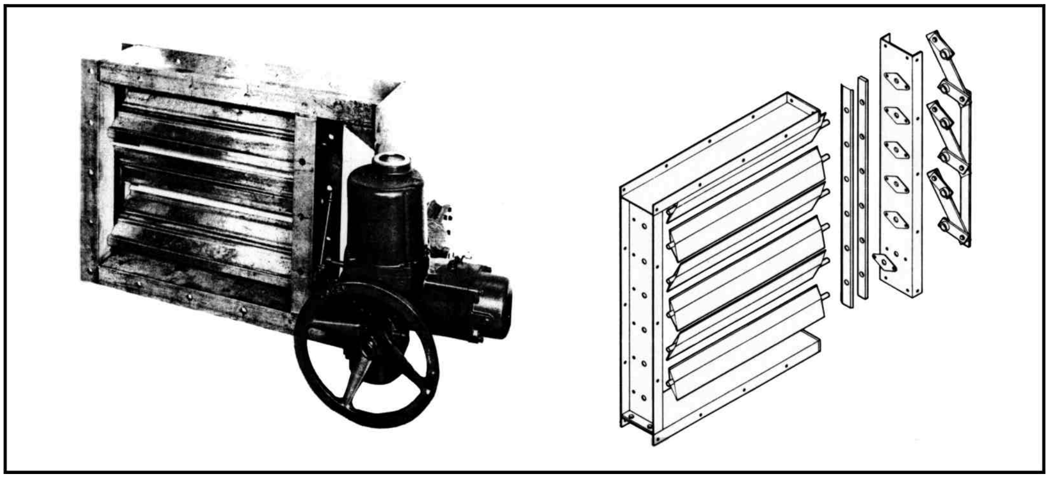

Figure 5.4 – Control Dampers.

5.2.3 ENGINEERED DUCTWORK

When sheet metal or piping thickness and reinforcement are established from engineering analysis rather than from ASME AG-1,[63] SMACNA standards,[4] or other referenced documents, the design should be in accordance with the criterion found in ASME AG-1, Sections AA and SA (AA-4000 and SA-4000).[63] In the engineering analysis, the following are examples of loads that should be considered potentially applicable to the system under consideration.

Additional dynamic loads (ADL). These loads result from system excitation caused by structural motion such as relief valve actuation, hydrodynamic loads due to design basis accidents (DBAs), small pipe break accidents, intermediate pipe break accidents, liquid "slosh," and other mechanical shock loads.

Constraint of free end displacement loads (T). These loads are caused by the constraint of free end displacement and are caused by thermal or other displacements.

Dead weight. These loads are the weight of equipment and ductwork, including supports, stiffeners, insulation, internally mounted components, externally mounted components and accessories, and any contained fluids.

Design pressure differential (DPD). These loads are dynamic pressures caused by DBAs, and intermediate or small break accidents.

Design wind (W). These loads are produced by design hurricanes, tornadoes, or other abnormal, infrequently occurring meteorological conditions.

External loads (EL). These are applied loads caused by piping, accessories, or other equipment.

Fluid momentum loads (FML). Loads other than those previously listed, such as the momentum and pressure loads caused by fluid flow.

- **Live load (L).** Loads occurring during construction and maintenance and other loads due to snow, ponded water, and ice.
- **Normal loads (N).** Loads including normal operating pressure differential, system operating pressure transients, dead weight, external loads, and inertia loads.
- **Normal operating pressure differential (NOPD).** The maximum positive or negative pressure differential that may occur during normal system operation, including startup and testing. These include the pressures resulting from normal airflow and damper or valve closure.
- **Seismic load.** These loads result from the operating basis earthquake or the safe shutdown earthquake (SSE). These seismic forces are applied in the direction that produces the worst-case stresses and deflections.

- **System operating pressure transient.** These overpressure transient loads are caused by events such as rapid damper or valve closure, rapid plenum or housing door closure, or other loads of this type that result in a short duration pressure differential (spike).

Additional information concerning the structural design and supports for ductwork and supports can be found in ASME AG-1, Section AA-4000.[63]

5.2.4 APPLICABLE CODES, STANDARDS, AND REFERENCES

There are many applicable codes, standards, and other references that are applicable to ductwork design. The following list includes major reference sources. A complete, detailed listing is available in ASME AG-1, Articles AA-2000 and SA-2000.[63]

1. Air Diffusion Council [38]
2. American Conference of Governmental Industrial Hygienists [2]
3. American Institute of Steel Construction [39]
4. American Iron and Steel Institute[40]
5. Air Movement and Control Association (AMCA) [41]
6. American National Standards Institute [42]
7. American Nuclear Society[43]
8. American Society of Heating Refrigeration and Air Conditioning Engineers [44]
9. American Society of Mechanical Engineers[45]
10. American Society of Nondestructive Testing[46]
11. American Society of Testing and Materials[47]
12. American Welding Society[48]
13. *U.S. Code of Federal Regulations* , Title 10, "Energy"[49]
14. Institute of Electrical and Electronics Engineers (IEEE) [50]
15. National Society of Corrosion Engineers[51]
16. National Electrical Manufactures Association (NEMA)[52]
17. Nuclear Construction Issues Group (NCIG)[53]
18. Sheet Metal and Air Conditioning Contractors National Association, Inc.[54]
19. Steel Structures Painting Council[55]
20. U. S. Government Printing Office[56]

5.2.5 MATERIALS OF CONSTRUCTION

Ductwork may be constructed from painted or coated carbon steel, galvanized steel, aluminum, stainless steel, or any combination of these materials as required to resist corrosion in the service environment. Glass-fiber-reinforced plastic (GFRP) and epoxy ducts have been used in corrosive environments where fire and safety requirements permit, and may be less expensive than stainless steel, lined carbon steel, or epoxy- or vinyl-coated carbon steel. Although the GFRP duct has been approved by the National Fire Protection Association (NFPA) and Underwriters' Laboratories (UL) for commercial and industrial use,[14] even high-temperature resins will soften under brief exposure to temperatures of 350 to 450 degrees Fahrenheit.[15] Softening of the GFRP duct can lead to rapid collapse or distortion, followed by loss of air cleaning function. GFRP and other plastic ductwork should not be used for Level 3, 4, or 5 construction and should be used with caution for Levels 1 and 2.

ASME AG-1, Article SA-3000,[63] provides ductwork and support material specifications, as well as testing requirement. See Chapter 2, Section 2.3.1.6, for material restrictions.

5.2.6 PAINTS AND PROTECTIVE COATINGS

Coating and paint requirements must be consistent with the corrosion that can be expected in the particular application and with the size of the duct. Corrosion- and radiation-resistant paints and coatings should, as a minimum, meet the requirements of ANSI N512[16] for "light exposure." Unless special spray heads are used, spray coating of the interior of ducts smaller than 12 in. in diameter is often unreliable because it is difficult to obtain satisfactory coating and to inspect for defects. The interior of a duct sized 8 in. and smaller cannot be satisfactorily brush-painted; therefore, dip coating is recommended. Ducts to be brush-painted should be no longer than 5 or 6 ft to ensure proper coverage. When special coatings such as high-build vinyls and epoxies are specified, the designer must keep in mind that difficulties in surface preparation, application, and inspection may increase the cost of coated carbon steel to the point that stainless or galvanized steel may be more economical. In addition, stainless or galvanized steel may provide better protection. It should be noted that high-build coatings and paints can be damaged during handling and shipping (as well as during construction, maintenance, repair, and testing/surveillance). Corrosion can begin under such damaged areas without the user's knowledge. Painted and coated ductwork must be inspected carefully during the painting (coating) operation, as well as on receipt. Galvanized coatings and plates should also be carefully inspected, particularly on sheared edges and welds.

5.2.7 SUPPORTS

5.2.7.1 ENGINEERED SAFETY FEATURE DUCTWORK SUPPORTS

The structural design of ESF ductwork supports must consider the service conditions that may be experienced during normal, abnormal, and the accident conditions (ASME AG-1, Article SA-4000).[63] The ESF ductwork must remain functional following dynamic loading events such as an earthquake. The ESF ductwork, including all attachments and accessories, must have their structural design verified by analysis, testing, or a combination of both. Qualification and design criteria for supports for ESF ductwork including vibration isolation are contained in ASME AG-1, Articles SA-4000 and AA-4000.[63]

5.2.7.2 NON-ENGINEERED SAFETY FEATURE DUCTWORK SUPPORTS

Where non-ESF ductwork runs adjacent to or over safety-related systems, equipment, or components, it should be supported in such a manner that, if failure of the supports were to occur during applicable DBAs [such as the design basis event (DBE) or SSE], the supports would not permit the ductwork to fall and damage any of these items. Articles SA-4000 and AA-4000 of ASME AG-1[63] provide the requirements for structural design of these supports.

Most nuclear facilities have requirements for support and attachment of items within the structures, including ductwork. These requirements are usually contained in the design/construction specifications or other governing site documents. In the absence of specific requirements, non-ESF ductwork can be hung, supported, and anchored in accordance with the recommendations of SMACNA "HVAC Systems Duct Design."[5]

5.2.8 THERMAL INSULATION AND ACOUSTIC CONSIDERATIONS

Thermal insulation, acoustic linings, and duct silencers are not permitted in ducts that carry or may carry moisture, corrosive fumes, or radioactive air/gas. Thermal insulation and acoustic treatment, if required, must be attached to the exterior of the duct and secured in such a manner that it cannot fall off during applicable DBAs.

Acoustic linings and silencers may be used in ductwork as long as the air being conveyed does not possess any of the characteristics described above, and provided they meet all of the duct system's quality assurance, environmental, and seismic requirements.

5.2.9 DUCTWORK LEAKAGE

The leaktightness of ductwork is extremely important, particularly in systems that carry or could potentially carry radioactive material. Duct leakage wastes power and thermal energy (the energy required to heat, cool, or dehumidify air), causes noise, prevents correct airflow to outlets from inlets, makes system balancing and temperature and humidity control difficult, and produces dirt collections and radioactive contamination at leakage sites.

Concerning ductwork equivalent to Levels 1 and 2, the Carrier Corporation's System Design Manual states:[17]

> Experience indicates that the average air leakage from the entire length of low velocity [positive pressure] ducts, whether large or small systems, averages around 10 percent of the supply air quantity. Smaller leakage per foot of length for larger perimeter ducts appears to be counterbalanced by the longer length of run. Individual workmanship is the

greatest variable, and duct leak rates from 5 to 30 percent have been found. High-velocity duct systems [Level 2] usually limit leakage to 1 percent.

The leak rates cited by Carrier[17] were for positive-pressure ductwork; if tested at the same degree of negative pressure, the same ducts would leak more. In tests conducted at a DOE facility,[20] sections of Level 2 ductwork tested alternately via the pressure-decay method at 2.5 in.wg positive and 2.5 in.wg negative showed no pressure loss in 15 min under positive pressure, but a loss of 2 in.wg in 15 min under negative pressure. This tendency for the same ductwork to leak substantially more under negative rather than positive pressure is confirmed by SMACNA.[21]

Even 1 percent is excessive for systems that carry or could potentially carry intermediate- to high-level radioactivity. Leak rates based on the percentage of airflow are meaningless and are subject to misinterpretation.

Procedures to determine the allowable leakage for ductwork are contained in ASME AG-1, Section SA, Non-mandatory Appendix SA-B[63]

Duct tightness can be satisfactorily tested by sealing off sections of the system and individually testing them. Leak testing should be performed in accordance with the methods provided in ASME AG-1, Article SA-5300, and Section TA.[63]

5.2.10 VIBRATION AND FLEXIBLE CONNECTIONS

Vibration and pulsation can be produced in an air or gas cleaning installation by turbulence generated in poorly designed ducts, transitions, dampers, and fan inlets, and by improperly installed or balanced fans and motors. Apart from discomfort to personnel, excessive vibration or pulsation can result in eventual mechanical damage to system components when vibrational forces become high or when acceleration forces (e.g., from an earthquake or tornado) coincide with the resonant frequencies of those components. Weld cracks in ducts, housings, and component mounting frames may be produced by even low-level local vibration if sustained, and vibrations or pulsations that produce no apparent short-term effects may cause serious damage after long duration.

Vibration produces noise that can range from unpleasant to intolerable. An important factor in preventing excessive vibration and noise is planning at the stage of initial building layout and space allocation to ensure adequate space is provided for good aerodynamic design of ductwork and fan connections. Spatial conflicts with the process and with piping, electrical, and architectural requirements should also be resolved during early design so that the compromises that are so often made during construction, which often lead to poor duct layout and resulting noise and vibration, can be avoided. Ducts should be sized to avoid excessive velocities while maintaining the necessary transport velocities to prevent the settling out of particulate matter during operation.

Fan vibration can be minimized via vibration isolators and inertial mountings. It should be noted that use of these devices must be carefully coordinated with the structural designers because seismic design requirements sometimes prohibit their use. Some structural designers require hard-mounting of fans where continued operation during and after an earthquake must be considered.

To minimize transmission of vibration from fans, flexible connections between fans and ductwork are often employed and recommended. These must be designed to resist the high static pressures often incurred in this class of system, particularly in those parts of the system under negative pressure. In addition, consideration must be given to the leakage and potential failure that can occur with flexible connections. Commercial applications commonly use heavy-duty canvas. Canvas is not suitable for nuclear facility applications. Consideration should be given to using at least two layers of a leak-proof material (e.g., rubber or neoprene, sometimes reinforced with higher-strength materials such as fiberglass).

Finally, the ductwork system must be balanced after installation, not only to ensure the desired airflows and resistances, but also to "tune out" any objectionable noise or vibration that may be inadvertently introduced during construction.